Unlocking the Future of Space Electronics with Advanced Manufacturing

---

European Space Agency

Joaquín Jiménez on behalf of

Dr Rita Palumbo
Internal Research Fellow in Advanced Manufacturing of EEE Components
TEC-ED Avionics and EEE Division
ESA/ECSAT

ACCEDE | ESCCON Seville, Spain 25-27/03/2025

OUTLINE

Introduction to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

05 Activities

06 Conclusions

OUTLINE

Introduction to AME 01

ESA Vision for AME 02

Technology Gaps 03

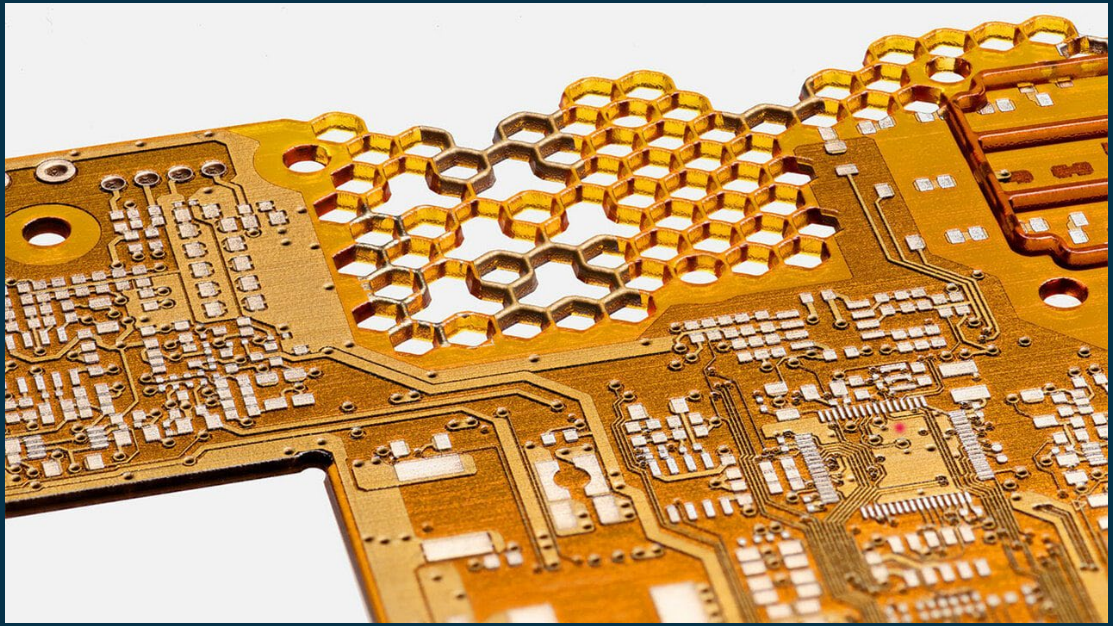
04 Roadmap

05 Activities

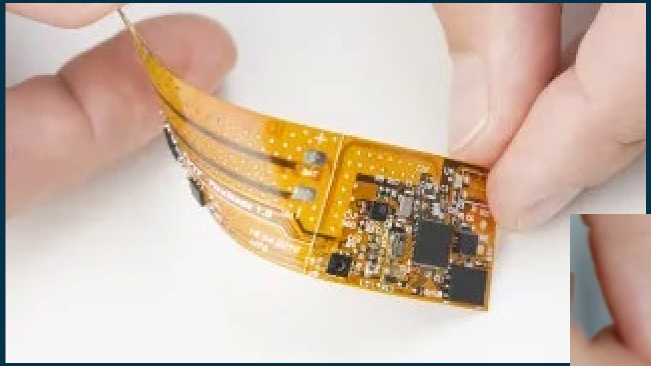
06 Conclusions

Advanced Manufacturing of Electronics (AME)

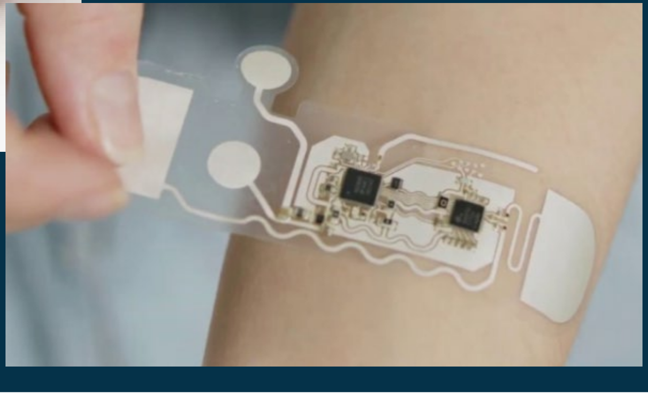
Cutting-edge technologies and processes used to manufacture electronics and components offering significant improvements in weight, miniaturization, customization, procurement time, technologies development and adoption, digital manufacturing, sustainability, and cost efficiency.



Nano Dimension



VTT



AME covers areas like 3D printing of electronics, hybrid electronics, flexible electronics, and novel materials for components and circuit boards, reshaping how electronics are designed, produced, and integrated into systems.

OUTLINE

Intro to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

05 Activities

06 Conclusions

ADVANCED MANUFACTURING AT ESA

- Advanced Manufacturing is being developed at ESA by many different teams and for many different applications:
  - **Materials** applications: TEC-MSP (Materials, Manufacturing and Assembly section)
  - **Mechanisms** applications: TEC-MSM (Mechanisms section)
  - **Structures** applications: TEC-MSS (Structures section)
  - **Thermal applications**: TEC-MTT (Thermal Control Section)
  - **Propulsion applications**: TEC-MPC (Chemical propulsion), TEC-MPE (Electrical propulsion)
  - **RF/MW applications**: TEC-EFE (RF passive hardware), TEC-EFA (antennas)
  - **Space Launchers** applications: STS-FP (Prometheus), STS-PVL (Vega)
  - …
  - And finally: **EEE components** applications: TED-ED (EEE and avionics division), TEC-EDC (Components Section)

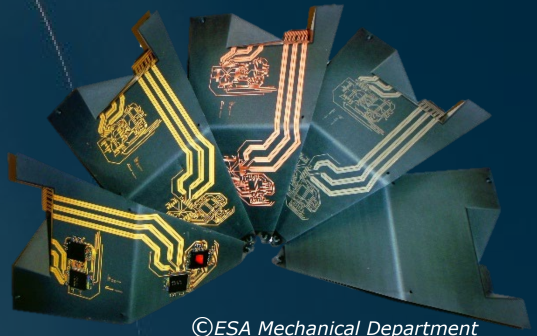
ESA Vision for AME


©NASA

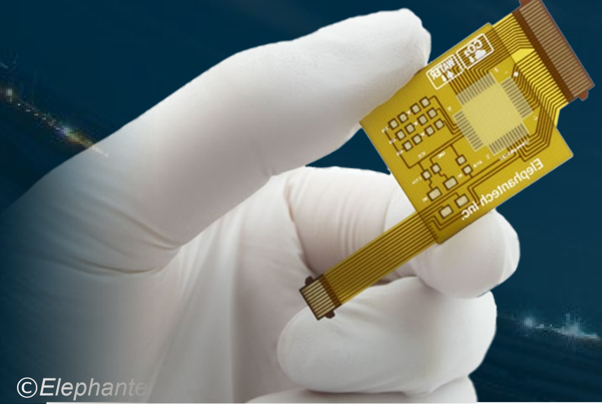
Introduce Advanced Manufactured Electronics (AME) to space

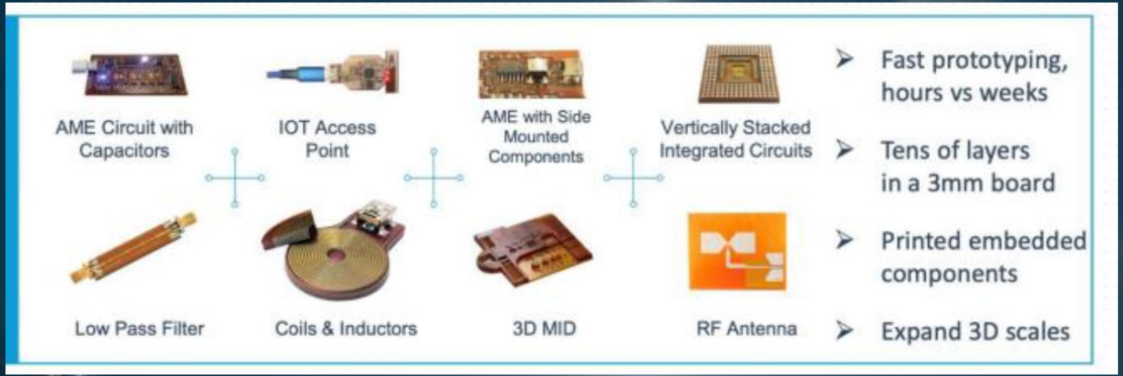
Building on ESA’s **TEC Mechanical Department** work on Advanced Manufacturing


©ESA Mechanical Department


©ESA Mechanical Department

Facilitate the industrialization of AME techniques and the development of a *European, local, one-stop-shop supply chain* for *sustainable, agile, and digital manufacturing* of electronics and components.


©Elephantech


AME Circuit with Capacitors

IOT Access Point

AME with Side Mounted Components

Vertically Stacked Integrated Circuits

Low Pass Filter

Coils & Inductors

3D MID

RF Antenna

- Fast prototyping, hours vs weeks
- Tens of layers in a 3mm board
- Printed embedded components
- Expand 3D scales

©Nano Dimension


Installation of roll-out solar arrays on the ISS - ©NASA/ESA

Introduce Advanced Manufactured Electronics (AME) to space.
The strategy is holistic and across all ESA directorates, to have a coordinated and shared roadmap.

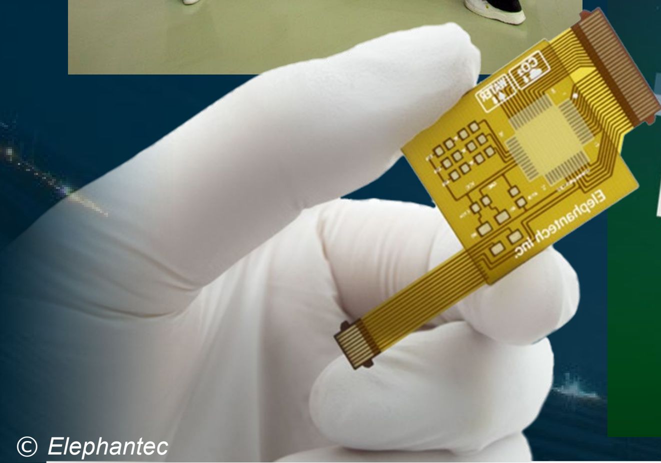

TEC


Space Transportation


Human and Robotic Exploration (HRE)


EOP


CSC Connectivity & Secure Communications



© Elephantec

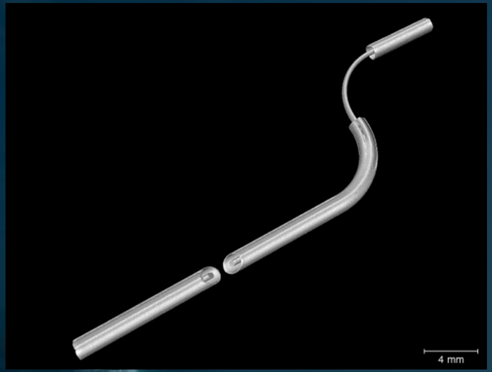
MOTIVATIONS FOR AME FOR SPACE

AME offers game-changing advantages for the **high-variety/low-volume space industry** and for prototyping:

- Digital manufacturing supports ESA digital transformation of the design process (integration with AI and digital twins).
- On-demand, rapid, agile manufacturing (procurement from 6-12 months to 24 hours) allows to quickly react to market needs.
- Possibility to develop an independent, European supply chain for electronics and components.
- Considerable reduction in costs.
- Relatively large weight reduction of samples.
- Significant decrease in environmental footprint.
- Access to Z dimension → unconventional 3D configurations, any shape, any substrate, miniaturization, embedding electronic functionality into the structure (e.g., walls of a satellite)
- Simpler packaging and monolithic integration potentially reduce failures in space.

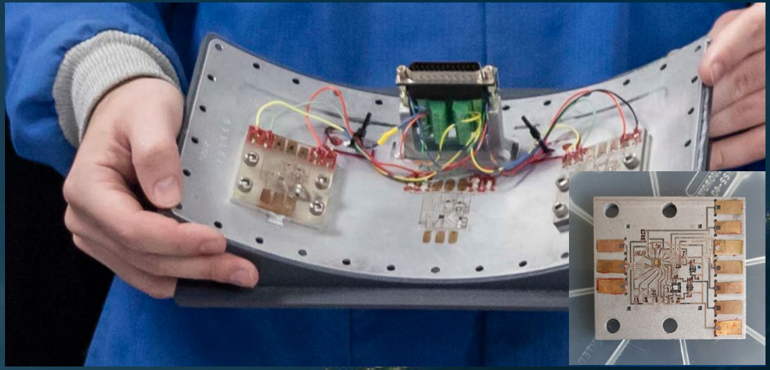
L3Harris Investigates 3D Printed Materials for Satellite Manufacturing.
Image courtesy of NASA's Glenn Research Center

Hybrid flexible Arduino.
© NextFlex



X-Ray scan of Coaxial cable 3D printed with Nano Dimension Dragon Fly IV.

Flexible white OLEDs for solid-state lighting.
© OLEDWorks



Hybrid printed circuits tested at the edge of space by NASA engineers in July 2023.
© NASA

INNOVATIVE CONCEPTS

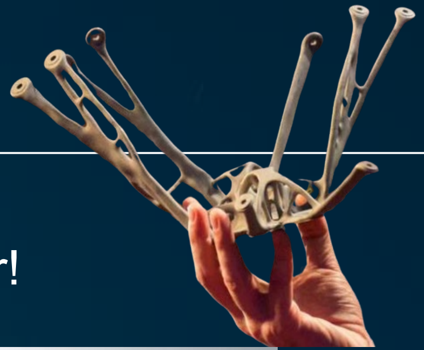
“The biggest mistake you can do with 3D printing is duplicating an existing design”

~ Tommaso Ghidini, H/Mechanical Department • TEC-M, TEDxESA 2015

Nature is additive!

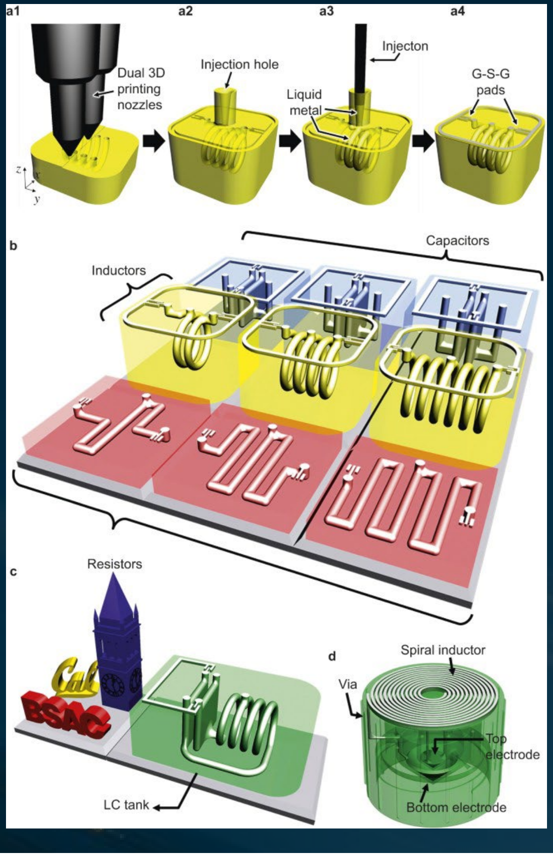
And from a structural point of view, it adds material only where needed

INNOVATIVE CONCEPTS

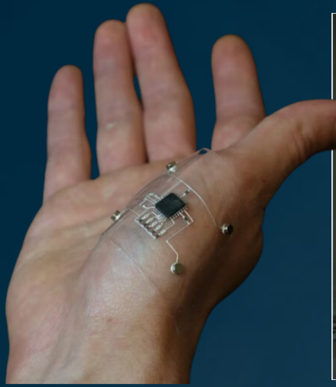


We need to learn to think in 3D also for electronics,

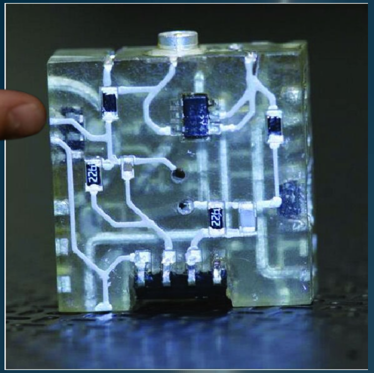
and develop new designs to make full use of the potentiality printing has to offer!



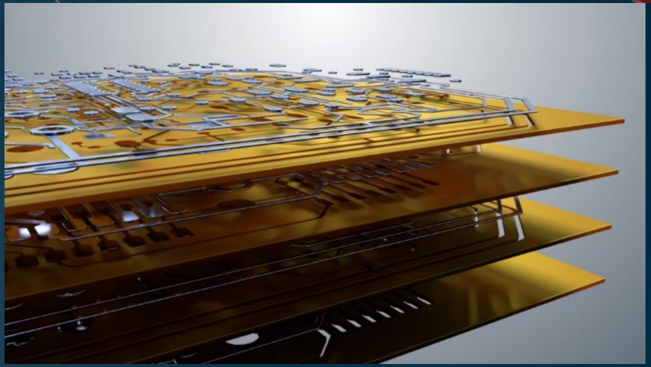
Wu, SY., Yang, C., Hsu, W. et al. *3D-printed microelectronics for integrated circuitry and passive wireless sensors. Microsyst Nanoeng* **1**, *15013 (2015)*



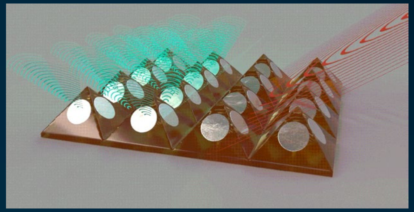
[1]



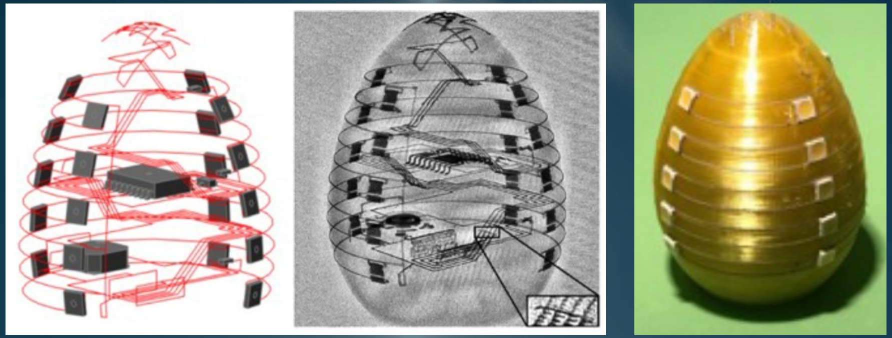
[4]



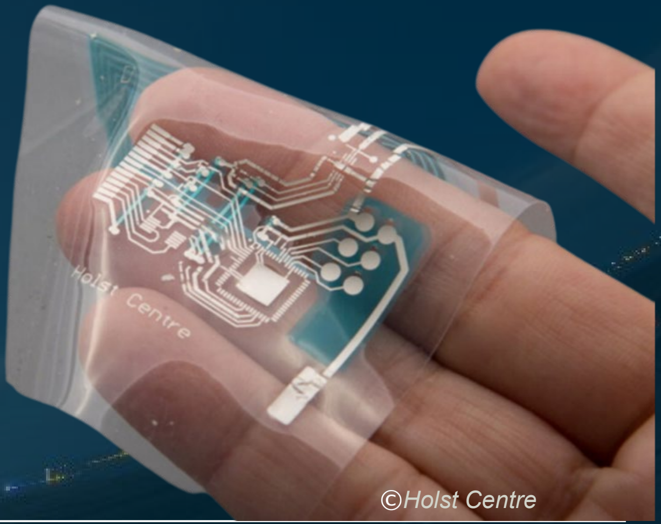
[5]



[3]



[2]



©Holst Centre

[1] Credit: Alex Valentine, Lori K. Sanders, Jennifer Lewis / Harvard University
[2] Demonstrator of 3D Printed Egg Timer | FAPS – University Erlangen-Nuremberg, Neotech
[3] Sphere phased array antenna – Nano Dimension
[4] 3D printed signal conditioning circuit. Eric Macdonald 2014
[5] Nano Dimension

The pivot to AME is not easy

But the payoff can be enormous.

OUTLINE

Intro to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

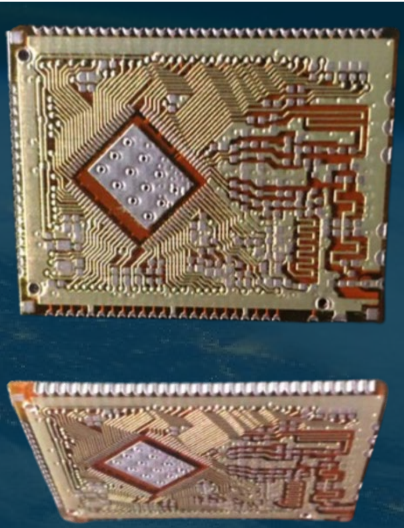
05 Activities

06 Conclusions

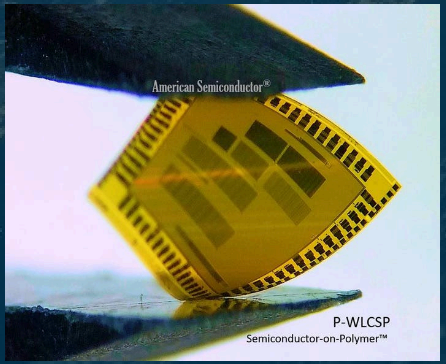
TECHNOLOGY GAPS

- Accuracy and resolution – most traditional printing methods allow >10 um feature size.
- Low mobility and device density (difficult to fabricate high-performance components).

  Hybrid systems **integrating AME with traditional electronics are the best solution.**
- High roughness can limit high-frequency RF applications.
- Standards for reliability and repeatability are still under development.
- No space heritage / space compatibility to be tested and developed.



Side mounting on PCBs, created by Nano Dimension DragonFly Pro



© American Semiconductor

Hybrid flexible Arduino. © NextFlex

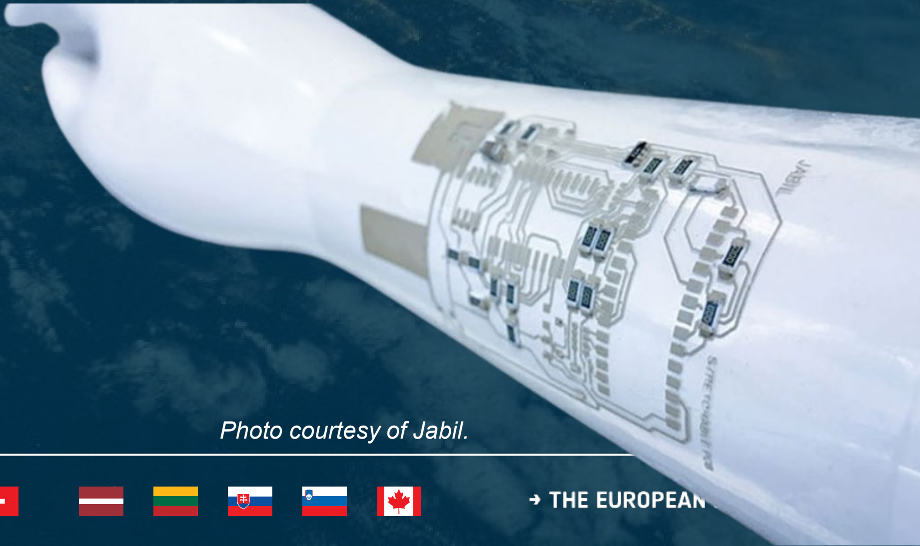


Photo courtesy of Jabil.

OUTLINE

Intro to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

05 Activities

06 Conclusions

ESA AME White Paper 2025

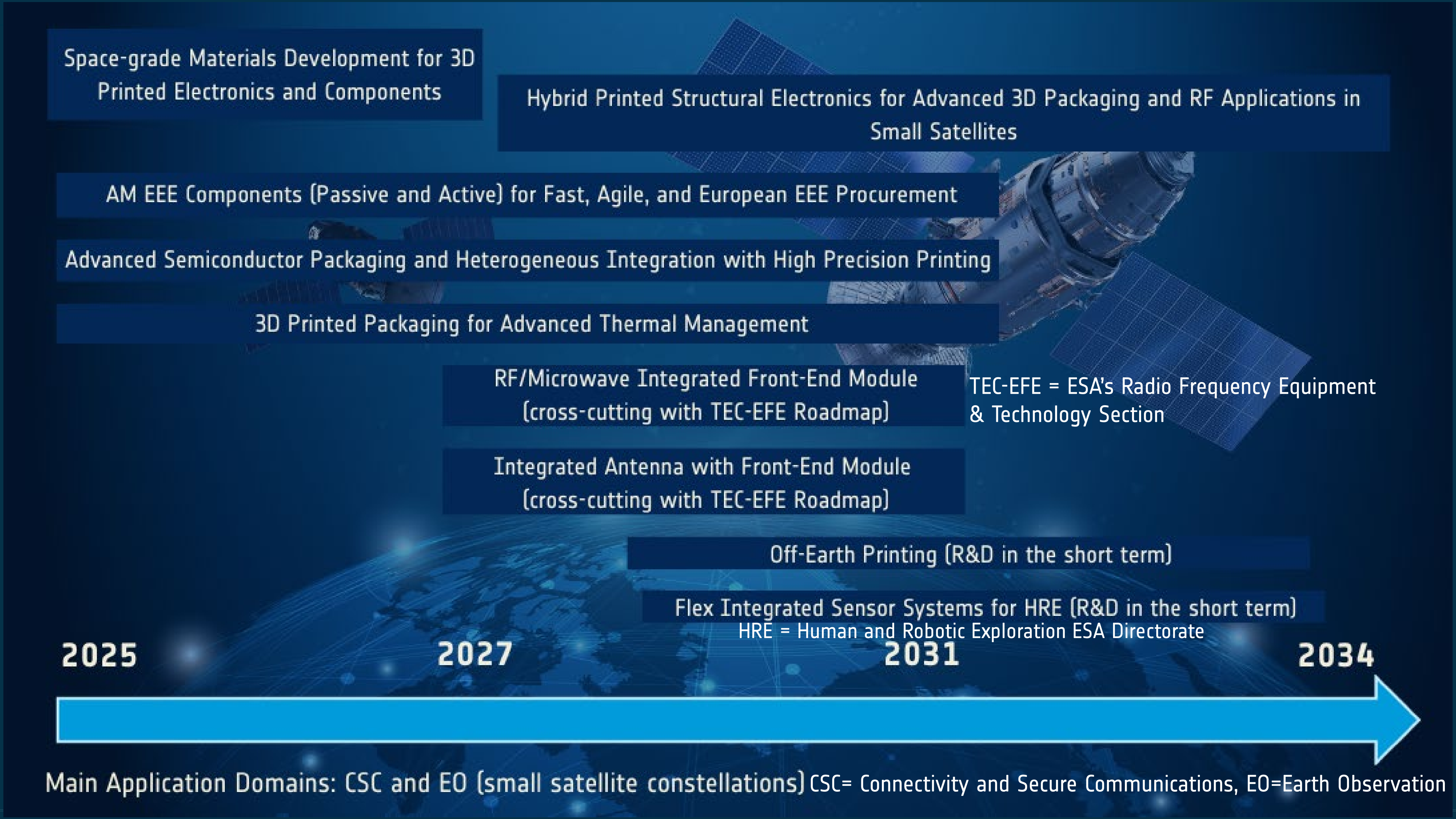
The paper is a living document which is being continuously updated.

ESA UNCLASSIFIED – For ESA Official Use Only

ADVANCED MANUFACTURING OF ELECTRONICS – A STRATEGY ROADMAP FOR EUROPEAN, SUSTAINABLE AND AGILE MANUFACTURING OF ELECTRONICS AND COMPONENTS

Prepared by	Rita Palumbo
Document Type	TN - Technical Note
Reference	ESA-TECED-TN-2024-003261
Issue/Revision	01 . 01
Date of Issue	12/02/2025

ESA AME ROADMAP



Space-grade Materials Development for 3D Printed Electronics and Components

Hybrid Printed Structural Electronics for Advanced 3D Packaging and RF Applications in Small Satellites

AM EEE Components (Passive and Active) for Fast, Agile, and European EEE Procurement

Advanced Semiconductor Packaging and Heterogeneous Integration with High Precision Printing

3D Printed Packaging for Advanced Thermal Management

RF/Microwave Integrated Front-End Module (cross-cutting with TEC-EFE Roadmap)

TEC-EFE = ESA's Radio Frequency Equipment & Technology Section

Integrated Antenna with Front-End Module (cross-cutting with TEC-EFE Roadmap)

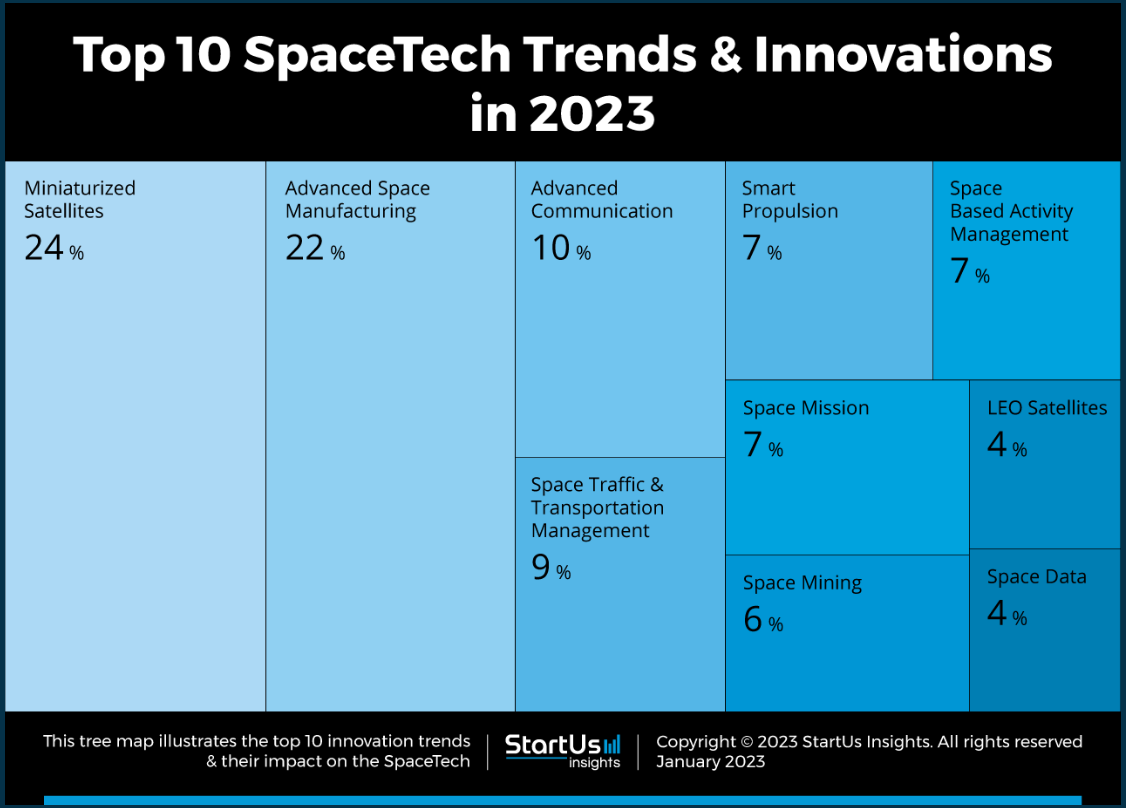
Off-Earth Printing (R&D in the short term)

Flex Integrated Sensor Systems for HRE (R&D in the short term)

HRE = Human and Robotic Exploration ESA Directorate

Main Application Domains: CSC and EO (small satellite constellations) CSC= Connectivity and Secure Communications, EO=Earth Observation

Priority areas of applications



This tree map illustrates the top 10 innovation trends & their impact on the SpaceTech

Copyright © 2023 StartUs Insights. All rights reserved January 2023

Target areas of applications:

1. **Small Satellites for Telecoms**
2. **Small Satellites for Earth Observation**

In Jan 2024, 8377 were orbiting the Earth.

Of these, 84% in LEO.

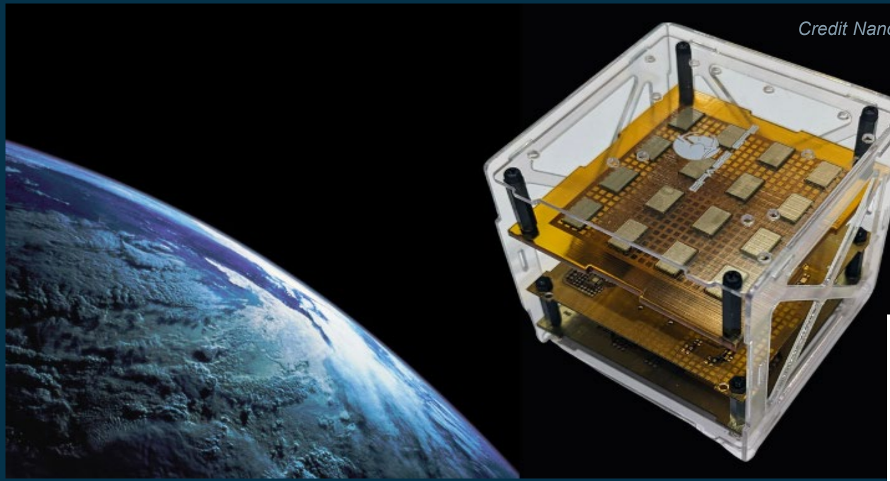
- 3135 for Communications
- 1052 for Earth Observation
- 383 for technology development
- 154 for navigation
- 108 for space science

80% of communication satellites are small satellites (i.e., mass<300 kg).
Overall, 72% of active satellites are small satellites.

Priority areas of applications – Small Satellites

Intelligent management of space is crucial for small satellites to house payloads while being as economical with size as possible.

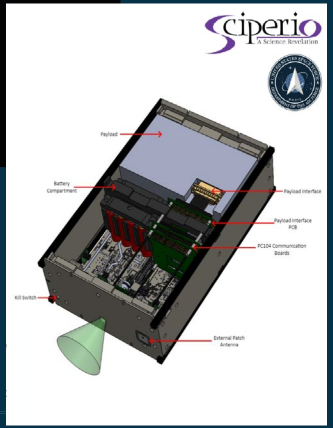
Constellation operators replace each deorbiting satellite within years with new designs based on the latest technologies to introduce new capabilities, which provides the perfect opportunity to experiment with novel AM technologies for electronics.



Credit Nano Dimension

→ Higher density, weight/volume optimization, and more space available inside the satellite

→ Possibility to print locally, on-demand, and quickly adapt to market needs



OUTLINE

Intro to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

05 Activities

06 Conclusions

RECOMMENDED AME ACTIVITIES

(Intended to be issued under different technology programmes - TDE, GSTP, Discovery Element)

HYBRID STRUCTURAL ELECTRONICS AND AM EEE COMPONENTS

Development of Space-grade Materials for 3D Printing of Electronics and Components in PCB-like Structures.

Advanced Manufactured Standalone Passive Components

Advanced Manufactured Standalone Active Components

Additive Manufactured elements for Photonic Integrated Circuits space environmental assessment

Advanced Manufacturing of 3D Printed Pseudocapacitive Electrodes for Supercapacitors *(shared with ESCC CTB Passive WG roadmap)*

3D Printed and Custom-design Multilayer Ceramic Capacitors *(shared with ESCC CTB Passive WG roadmap)*

Printed Harness for Satellites

3D Printed Phased Array Antennas *(ARTES proposal 2025 submitted with TEC-EFA)*

ADVANCED PACKAGING

High Precision RDL Printing for Wafer-Level Packaging and Heterogeneous Integration

Ceramic Composites and Copper 3D Printed Packaging for Semiconductor Thermal Management

PASSIVES AND RF PASSIVES

Miniaturized integrated Ka-band passive equipment *(ARTES proposal 2025 submitted with TEC-EFE, TEC-MSP)*

RUNNING AME ACTIVITIES

Investigation of Printing EEE (*) Components using Additive Manufacturing Methods

The Manufacturing Technology Centre (MTC) (UK)

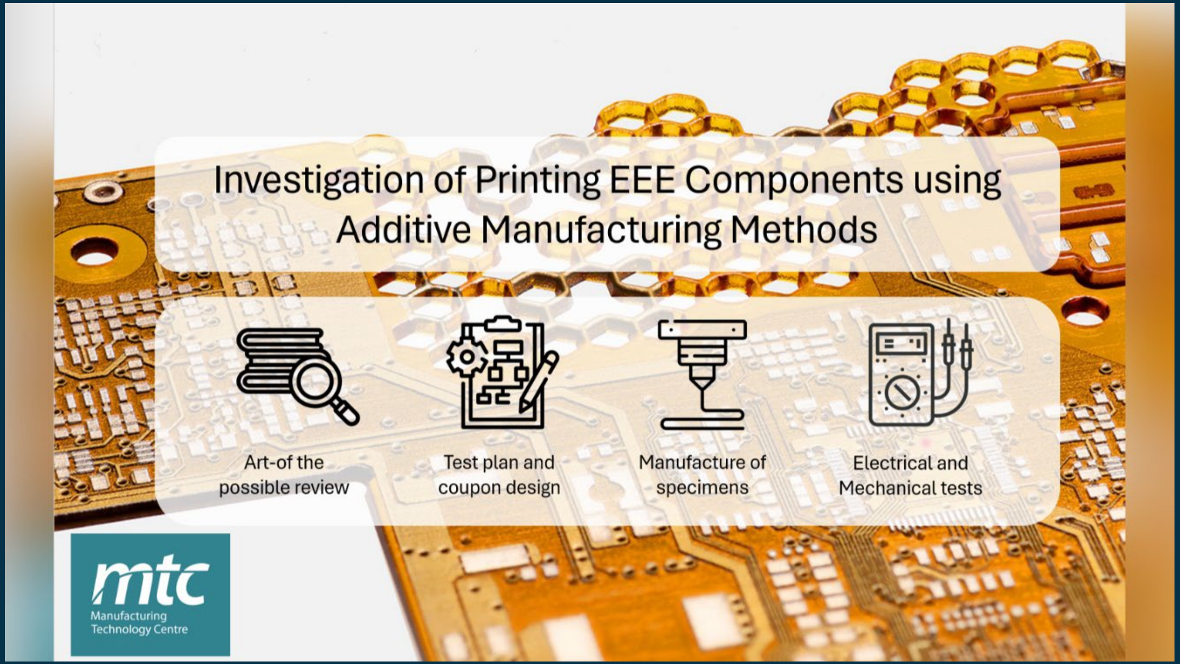
Budget: 175k€

Discovery Programme | OSIP Idea Id I-2023-03422 |

Open Discovery Ideas Channel

Early Technology Development

Development of novel technologies integrating additive manufacturing (Nano Dimension LDM inkjet printer) with contact printing methods (e.g., screen printing) for EEE components (capacitors, inductors, resistors) and assessing space compatibility. By adopting this approach performance benefits include the design of novel configurations, weight saving, miniaturization, and the flexible use of substrates.



Investigation of Printing EEE Components using Additive Manufacturing Methods

Art-of the possible review

Test plan and coupon design

Manufacture of specimens

Electrical and Mechanical tests

(*) EEE: Electrical, Electronic, and Electromechanical

RUNNING AME ACTIVITIES

GHz Organic Printed Transistors - “GHioZa”

Istituto Italiano di Tecnologia (IIT) (IT)

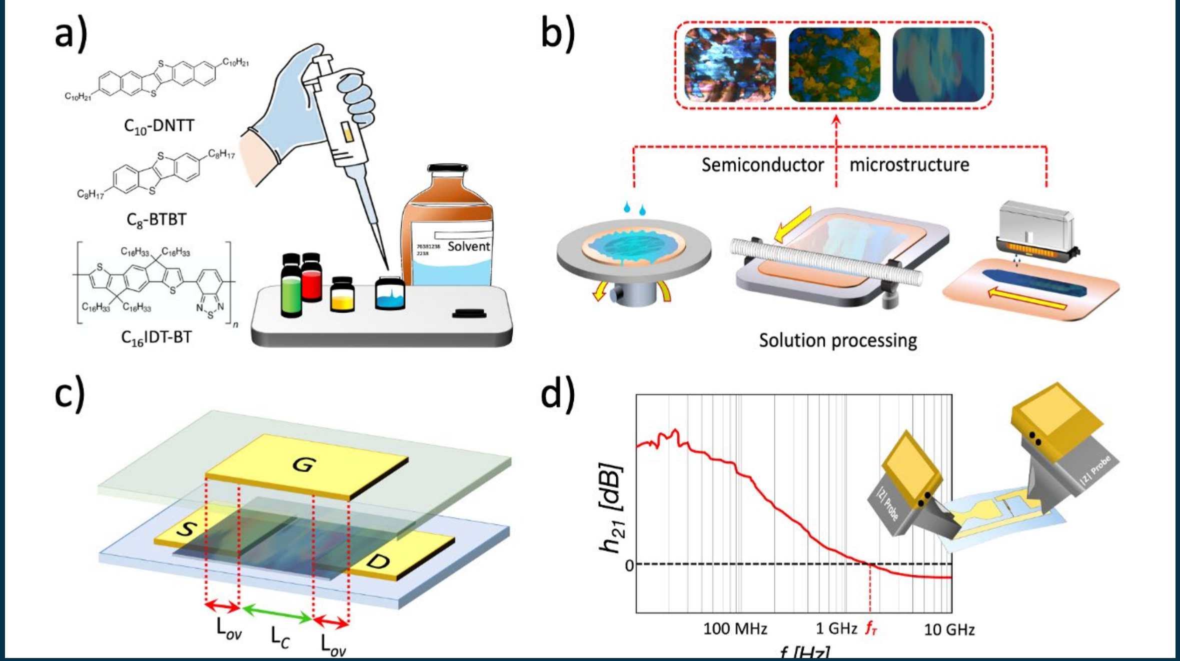
Budget: 170k€

Discovery Programme | OSIP Idea Id I-2023-07677 |

Open Discovery Ideas Channel

Early Technology Development

Demonstrating for the first time organic transistors based on printable semiconductors operating in the Ultra-High Frequency (UHF) bandwidth (300 MHz – 3 GHz) and assessing their robustness to space environment.



RUNNING AME ACTIVITIES

Integrated Printed and EEE Components in a Miniaturised Thin Film Sensing System for Planetary Exploration

University of Swansea's Welsh Centre for Printing and Coating (WCPC)

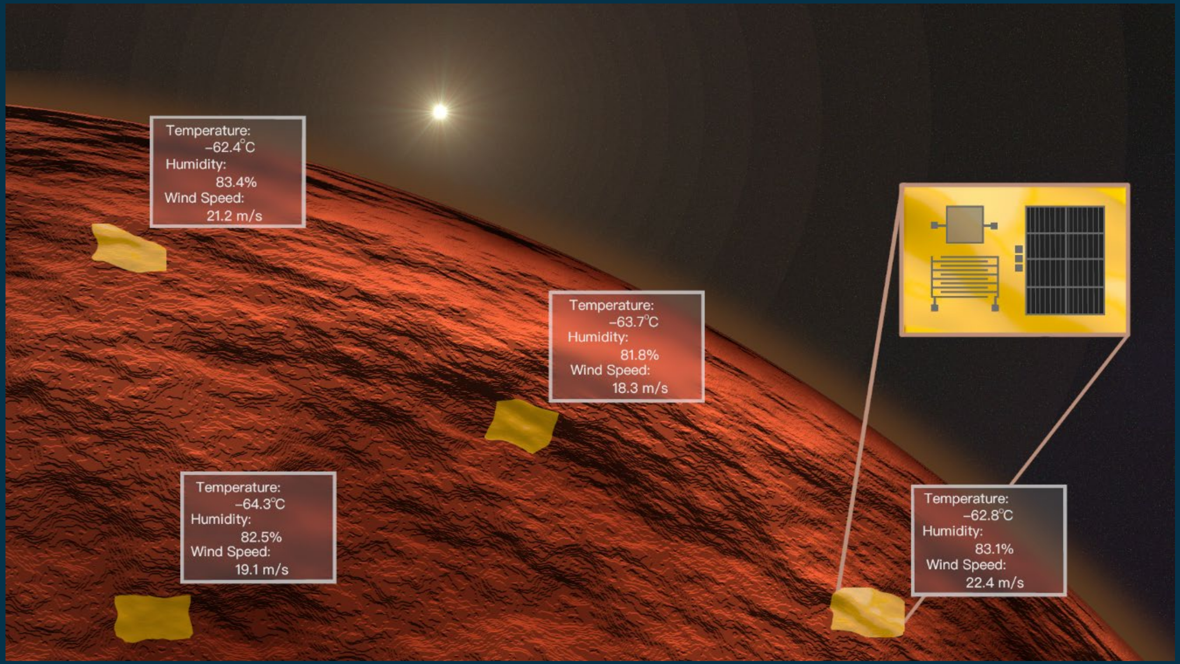
Budget: 90k€

Discovery Programme | OSIP Idea I-2023-07775 |

Open Discovery Ideas Channel

Co-sponsored research

Developing a proof-of-concept thin-film sensor platform system, integrating printed and silicon elements, through aerosol jet and inkjet printing. Offering a self-contained technology suitable for large area deployment over extraterrestrial bodies as "sensor confetti".



RUNNING AME ACTIVITIES

Manufacturing and repairing of micro-patterns for electronics in micro-gravity through High Precision Capillarity Printing (HPCAP)

MAANA Electronics and Hummink (LU)

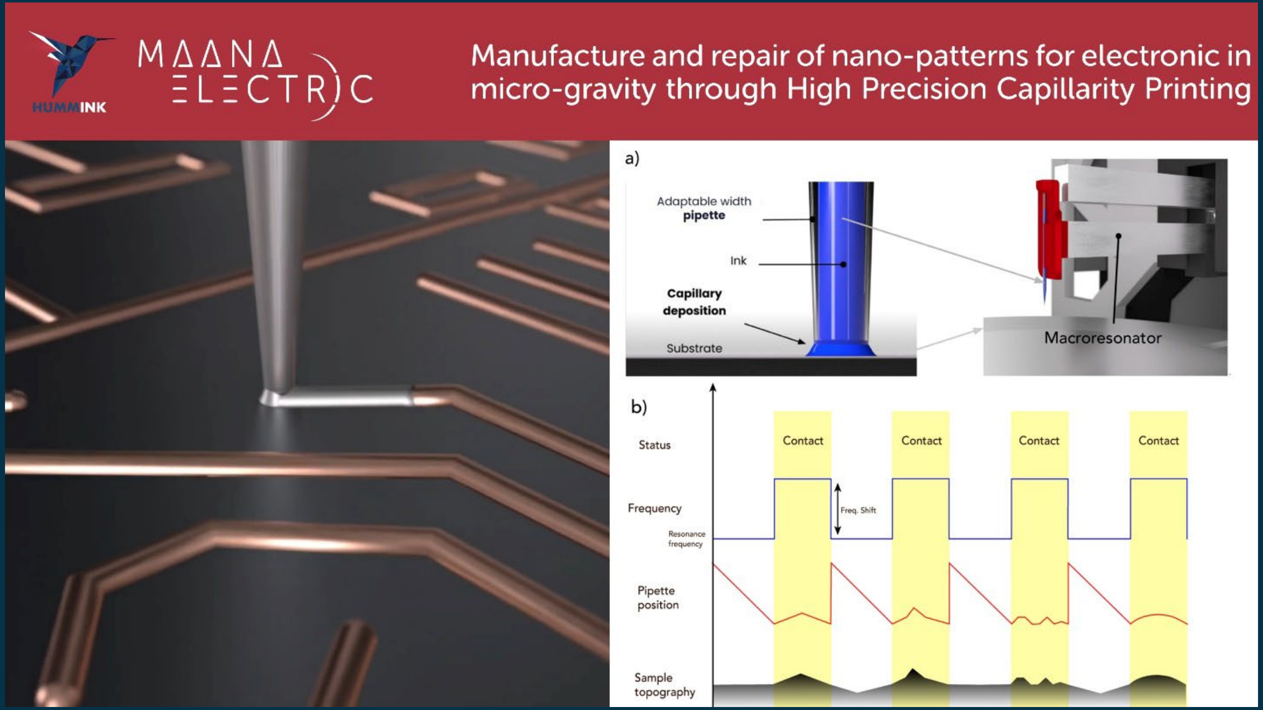
Budget: 175k€

Discovery Programme | OSIP Idea I-2023-09669 |

Open Discovery Ideas Channel

Early Technology Development

High Precision Capillarity Printing (HPCAP) can deposit any material on a substrate with precision from 50um to 100nm. The capillarity deposition is not affected by gravity, and surface tension retains the printed pattern regardless of their orientation.
The activity aims to develop a prototype of the printer able to work in microgravity.



HUMMINK MAANA ELECTRIC

Manufacture and repair of nano-patterns for electronic in micro-gravity through High Precision Capillarity Printing

OUTLINE

Intro to AME 01

ESA Vision for AME 02

Technology Gaps 03

04 Roadmap

05 Activities

06 Conclusions

CONCLUSIONS

- Advanced Manufacturing for Electronics (AME), such as printing and additive manufacturing, has the potential to revolutionize EEE components and electronics development and disrupt the future of space industry.
- The high-variety low-volume space industry particularly benefits from the advantages of AME.
- Accelerated procurement time, independent European supply chain, sustainability, low costs and miniaturization are among the main motivations for AME adoption.
- Areas of application of high interest include small satellites for telecommunications and earth observation.
- ESA is introducing a long-term roadmap to support and facilitate the industrialization of AME technologies.
- Activities to accelerate AME development and adoption in space are being proposed in a GSTP Funding Scheme.
- Organizations are welcome to submit proposals through the **OSIP** platform (*Open Space Innovation Platform*)
- Organizations are invited to register on **esa-star** (*System for Tendering And Registration*) and monitor the platform for relevant Invitations To Tender.

esastar-publication-ext.sso.esa.int

OSIP platform: ideas.esa.int

European Data Handling & Data Processing Conference

EDHPC 2025 13th – 17th October 2025 Elche (Spain)

International forum covering diverse aspects:

- on-board computers,
- on-board data handling systems,
- on-board data processing m
- microelectronics for space applications, platform and payload applications (RF and optical).

Objectives:

- Foster cooperation between different experts.
- Discuss architectures, reference designs, microelectronics component developments, performance of current and future data handling/ processing hardware for space.
- Establish closer links between industry and international / national space agencies, to enable further developments in these fields

EDHPC 2025

European Data Handling & Data Processing Conference

13 - 17 October 2025 | Elche | Spain

Abstract Submission Extended 31st of March

Thank you for your attention!


ESA/ECSAT UK


ESA/ESTEC NL

Contact us for any questions or information:

- **Dr. Rita Palumbo** Rita.Palumbo@esa.int
- **Mr. Joaquín Jiménez Carreira** Joaquin.Jimenez@ext.esa.int
- **Dr. Jürgen Beister** Juergen.Beister@esa.int

Joaquín Jiménez Carreira on behalf of

Dr Rita Palumbo
Internal Research Fellow in Advanced Manufacturing of EEE Components
TEC-ED Avionics and EEE Division
ESA/ECSAT

ACCEDE | ESCCON Seville, Spain 25-27/03/2025